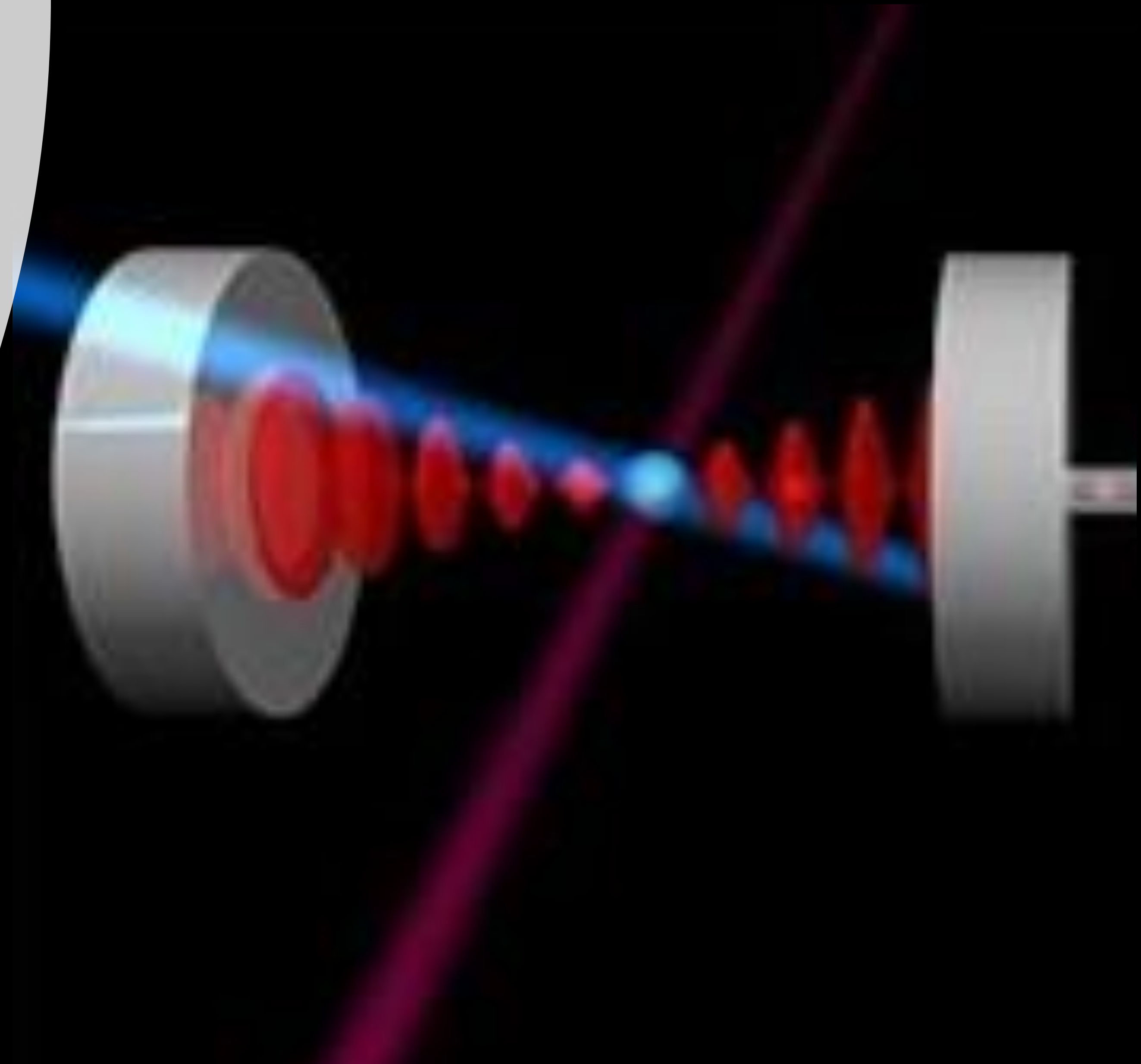
Cavity-enhanced Ion-Ion Remote Entanglement

Shaobo Gao, William Hughes, Joseph Goodwin, David Lucas

University of Oxford

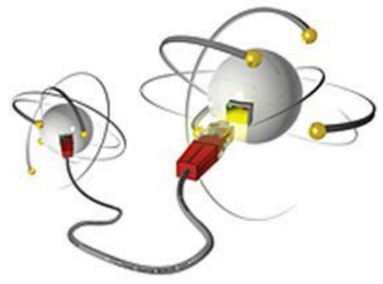


content

- Ion-ion remote entanglement
- Cavity-enhanced Raman transition
- Noise process and temporal property of photons
- Result:
  - Optimising cavity parameters
  - Technical challenge

Ion-ion remote entanglement

- Quantum entanglement is the central resource behind quantum information science



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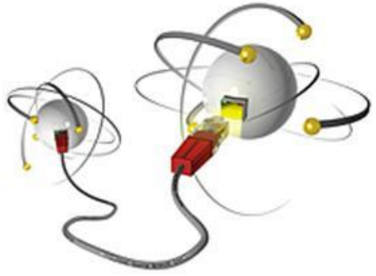
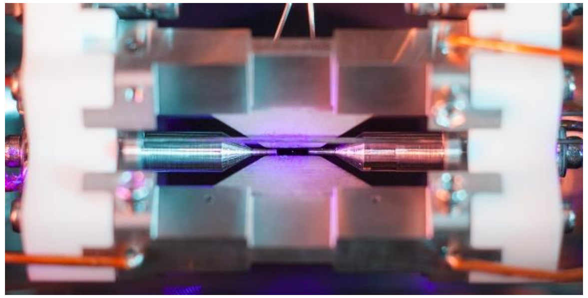
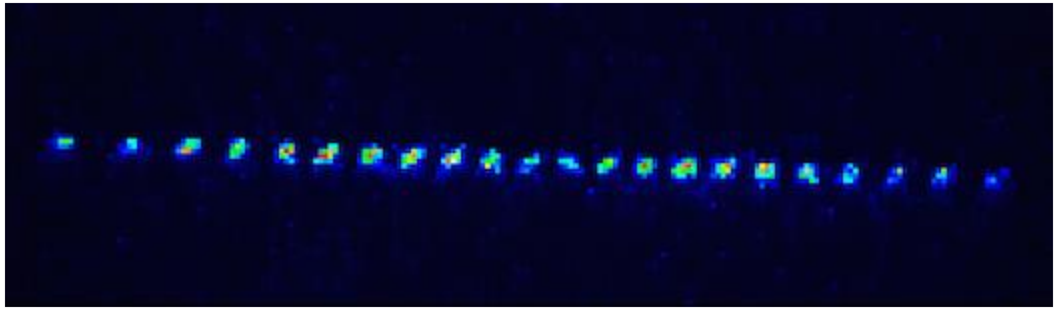


- Ion trap is advantageous for quantum information processing



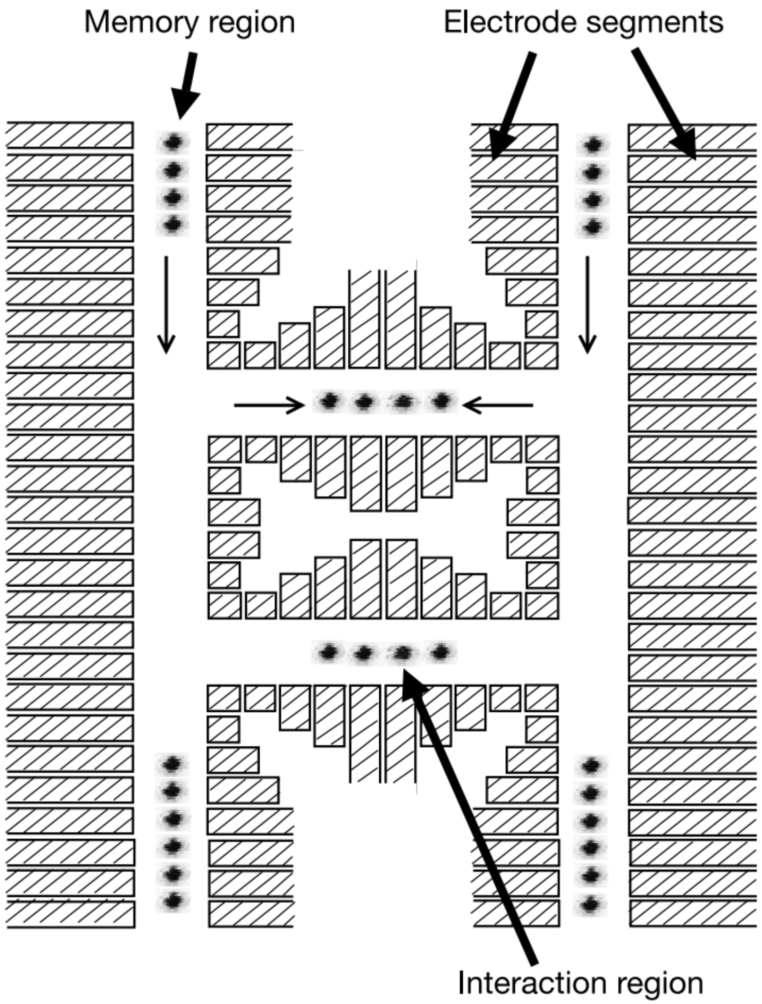
- Local qubit entanglement is confronted with practical limits to the number of qubits that can be reliably controlled



Ion-ion remote entanglement

Two main approach to achieve remote entanglement:

1. Move qubits between modules[1]



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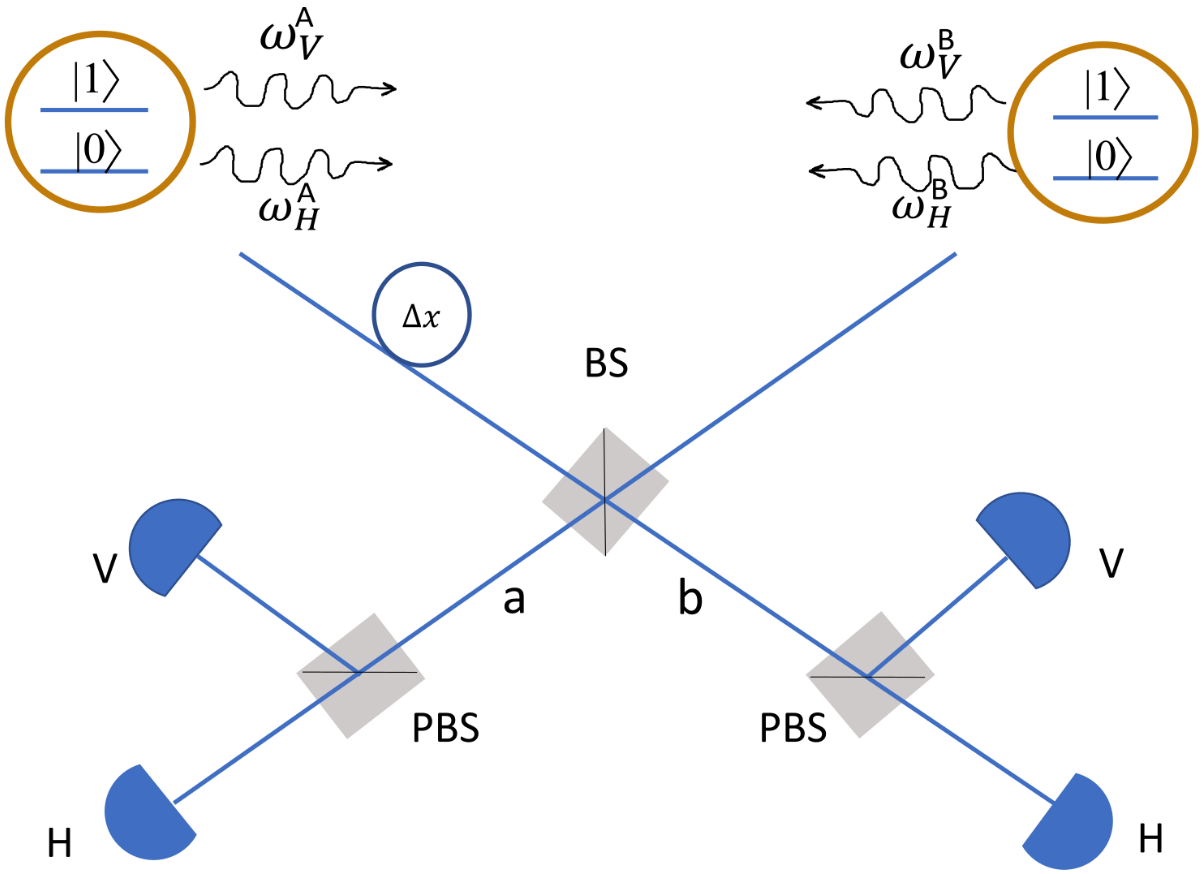

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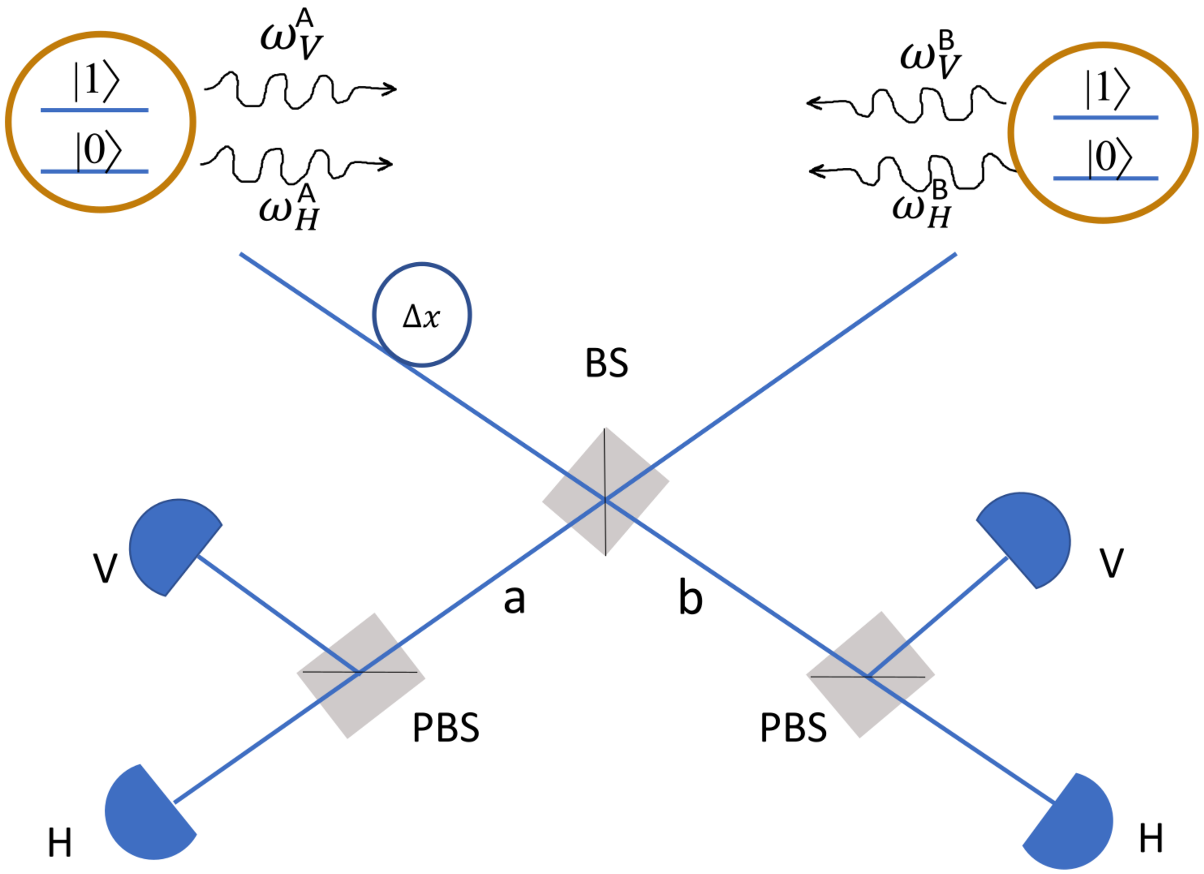

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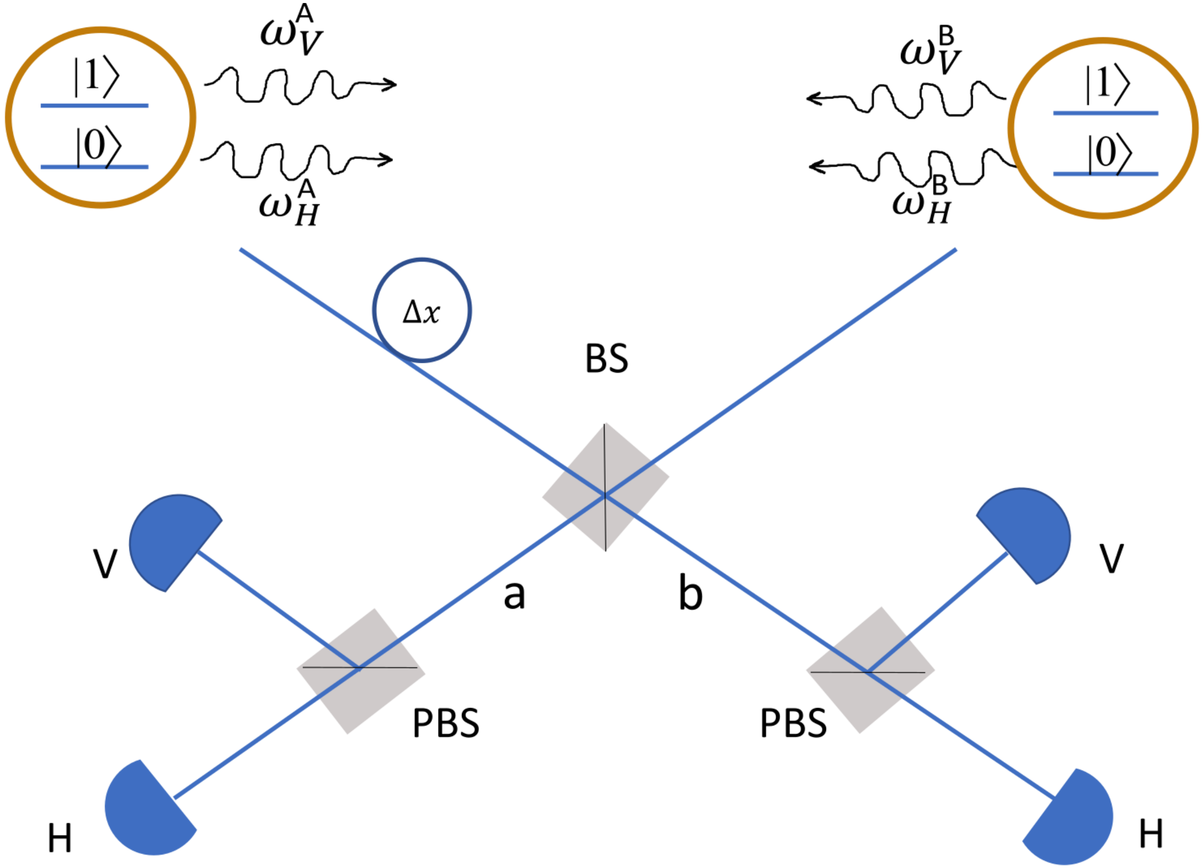
   - Photon collected by cavity
     a) Direct excitation
     b) Raman transition



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Cavity-enhanced Raman transition

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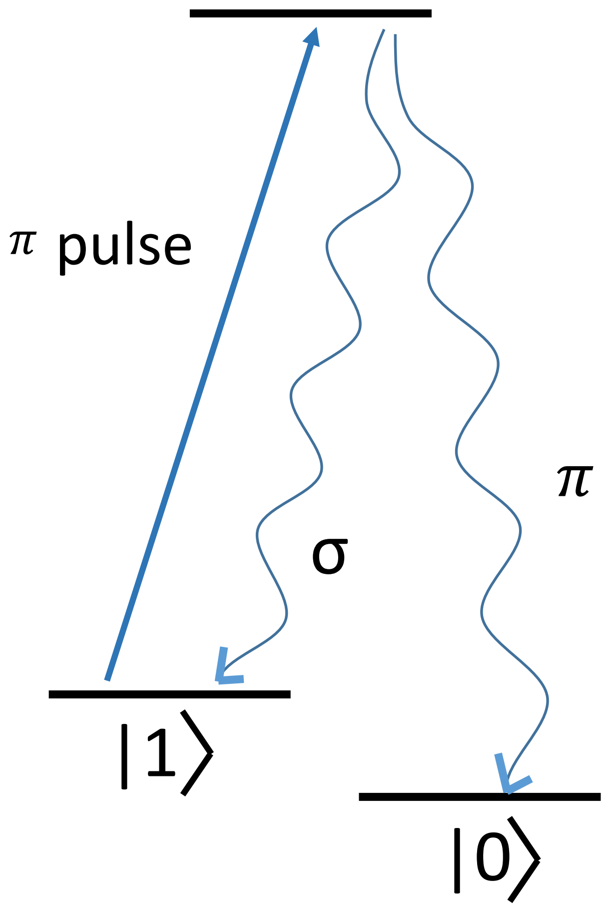
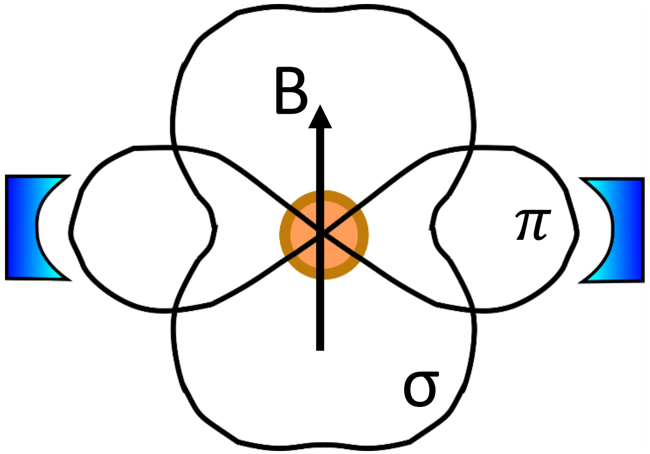
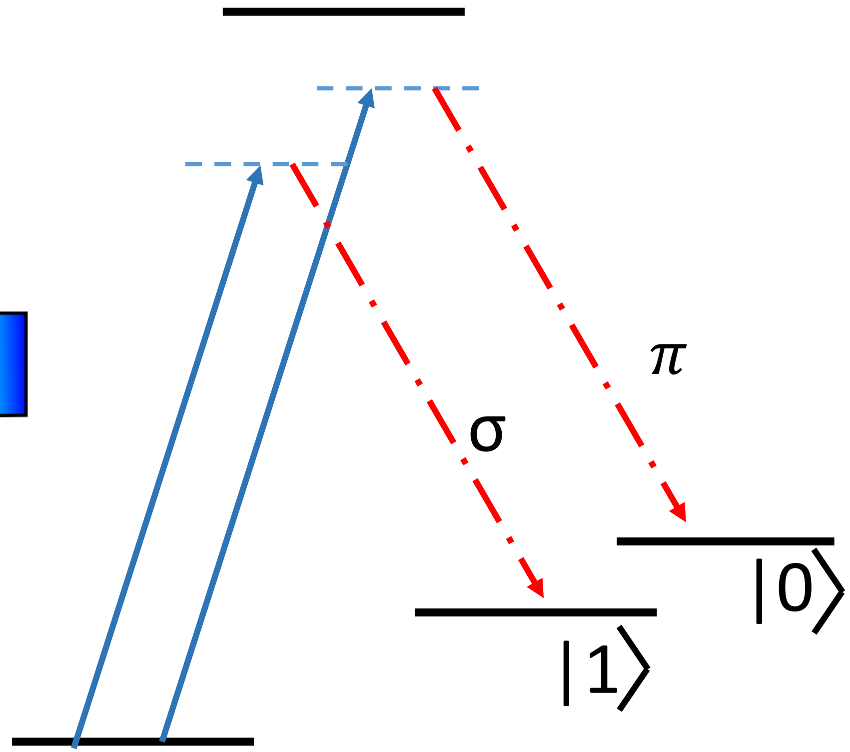




$\pi \rightarrow V$
$\sigma \rightarrow H$

Cavity-enhanced Raman transition



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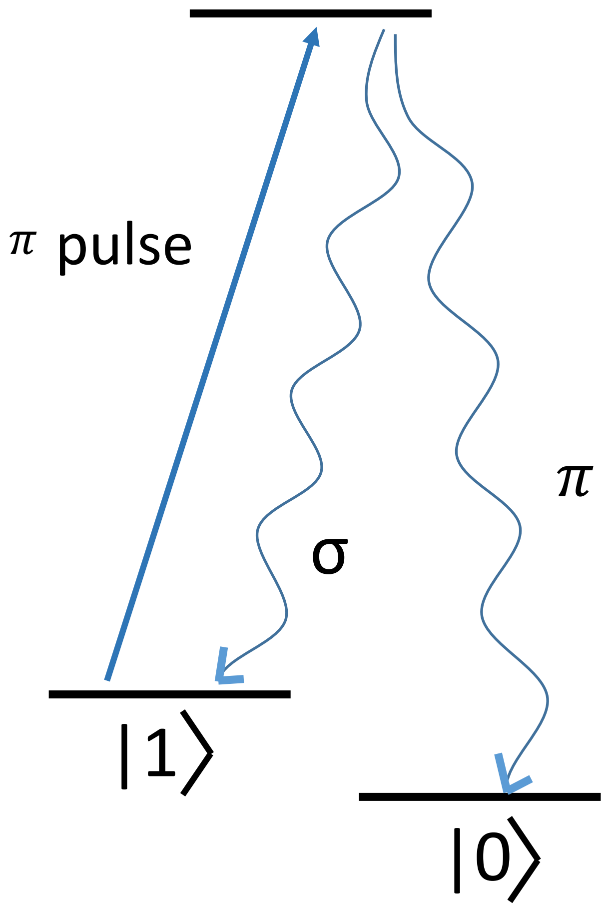

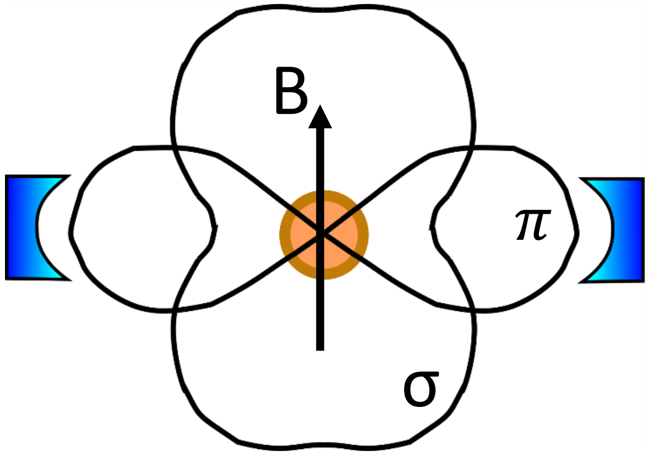

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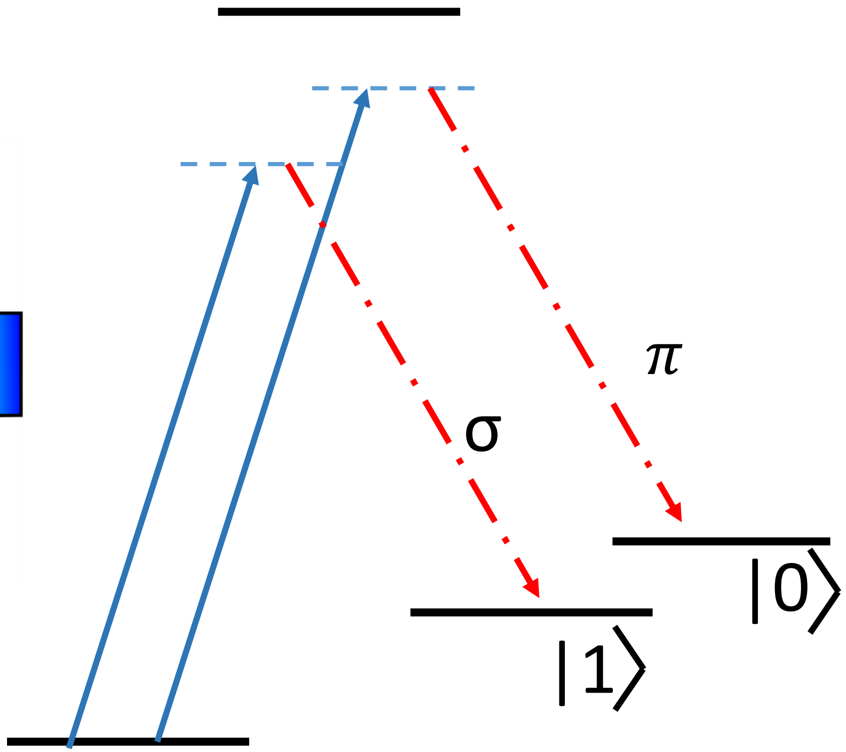

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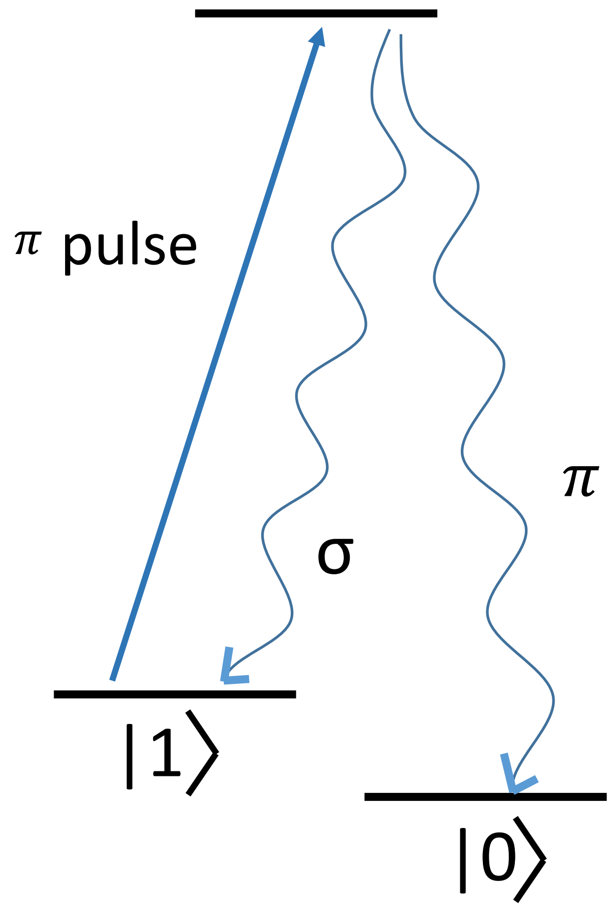

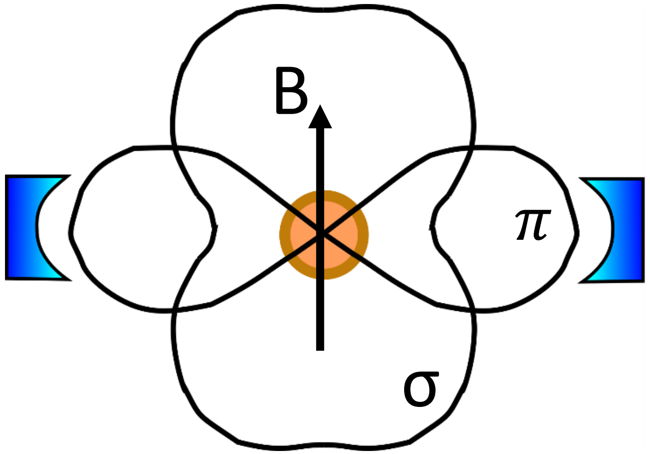

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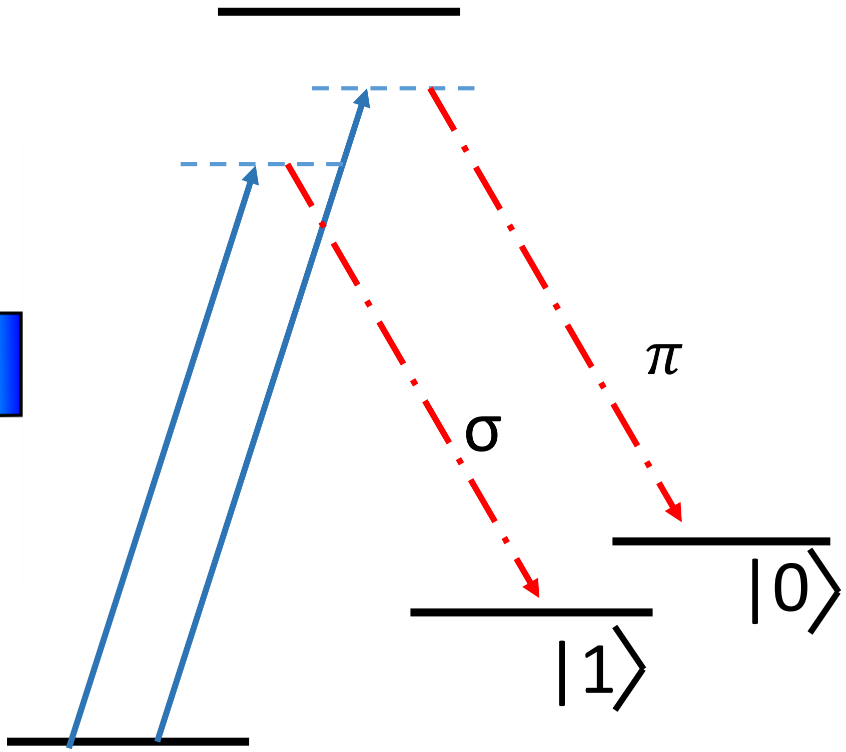
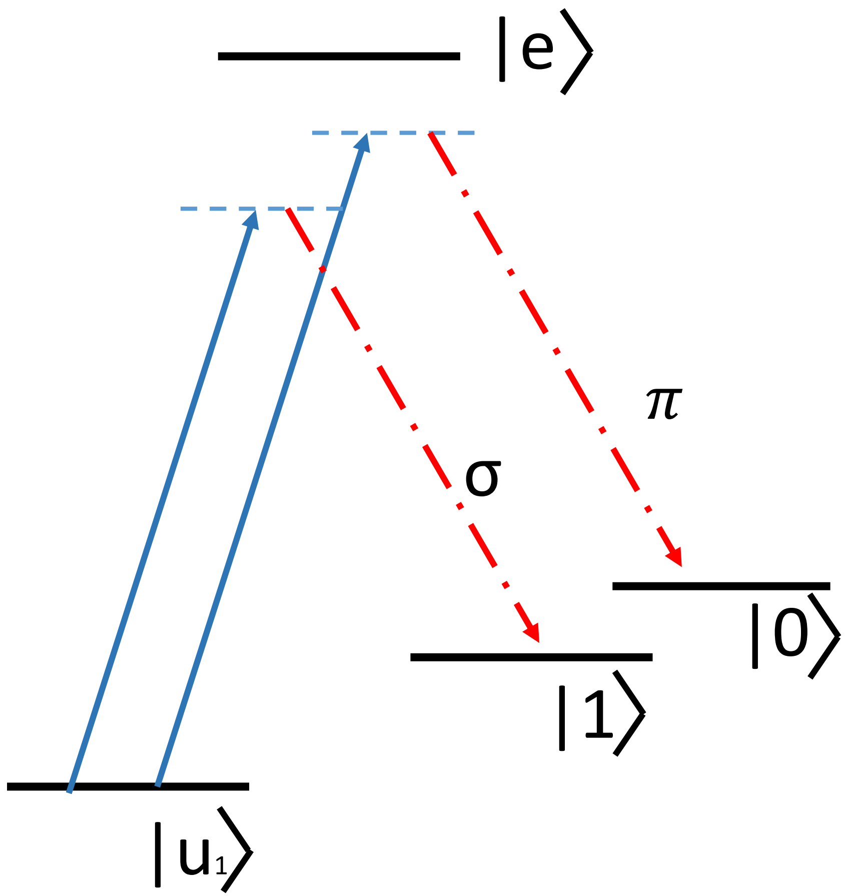


Cavity-enhanced Raman transition

Hamiltonian

$$H_{int} =(\hbar g_H e^{i\Delta_H t}\sigma_{e0}a_H^{+} + \hbar\frac{\Omega_H}{2}e^{-i\Delta_H t}\sigma_{u_1 e}$$
$$+ \hbar g_V e^{i\Delta_V t}\sigma_{e1}a_V^{+} + +\hbar\frac{\Omega_V}{2}e^{-i\Delta_V t}\sigma_{u_1 e}) + c.c.$$

Cavity-enhanced Raman transition

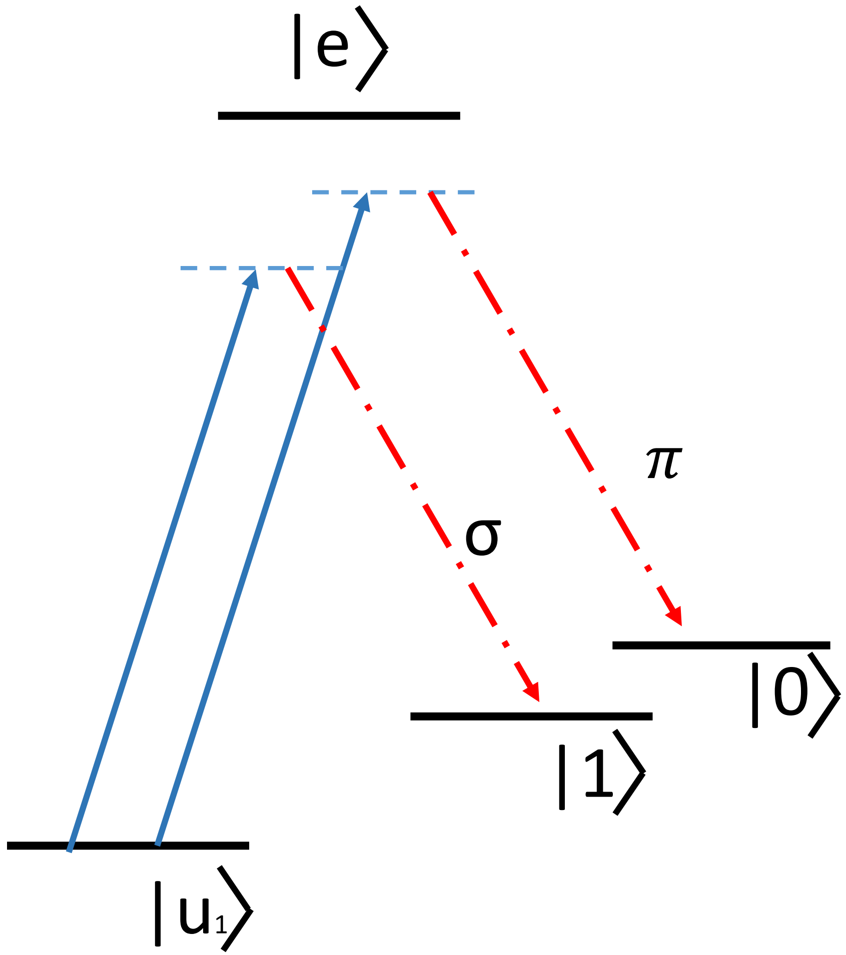


Advantage:

- Flexible choice of frequency,
- Continuous driving laser,
- controllable photon wave packet, .

Noise process and temporal property of photons

Noise process:



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Noise process:

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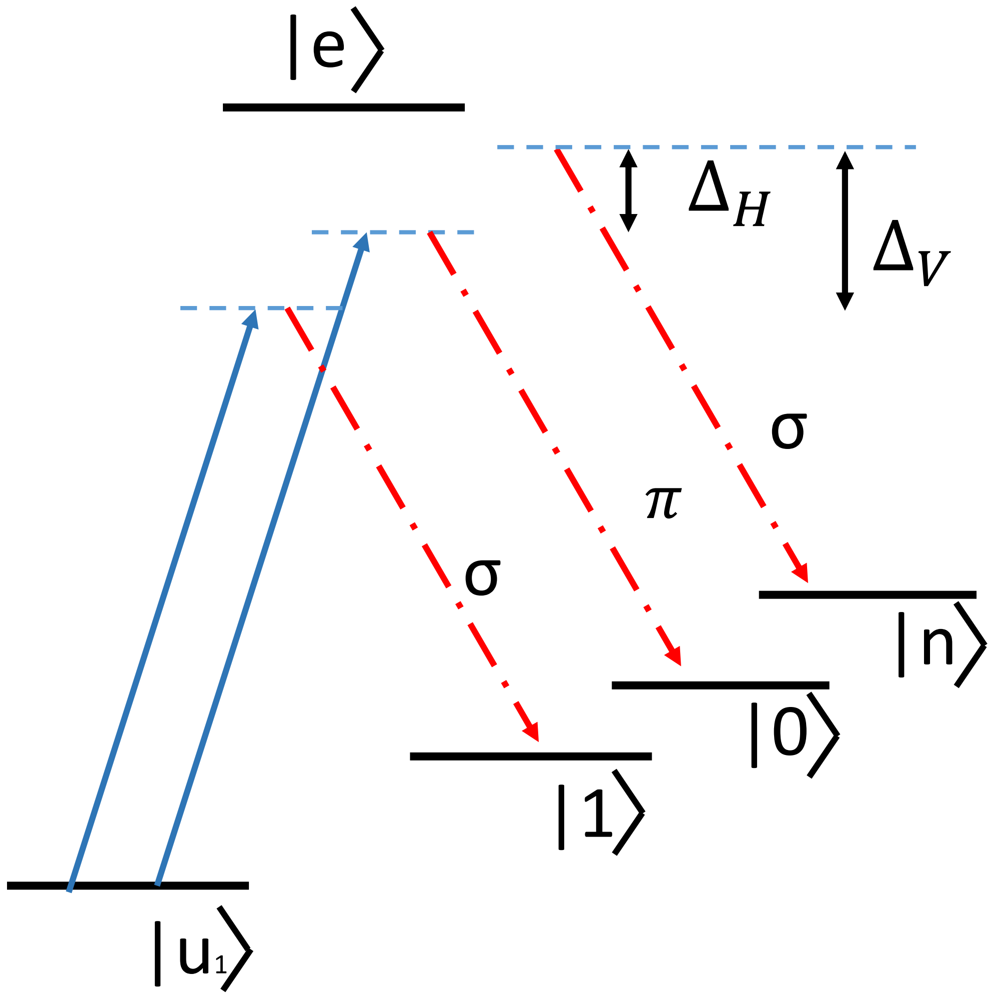
  infidelity $\approx \frac{2\kappa^2}{\Delta_H^2+\Delta_V^2}$



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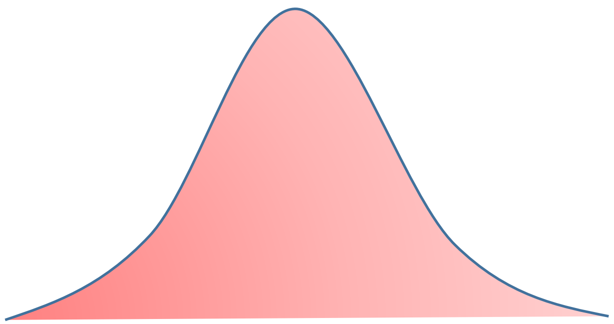

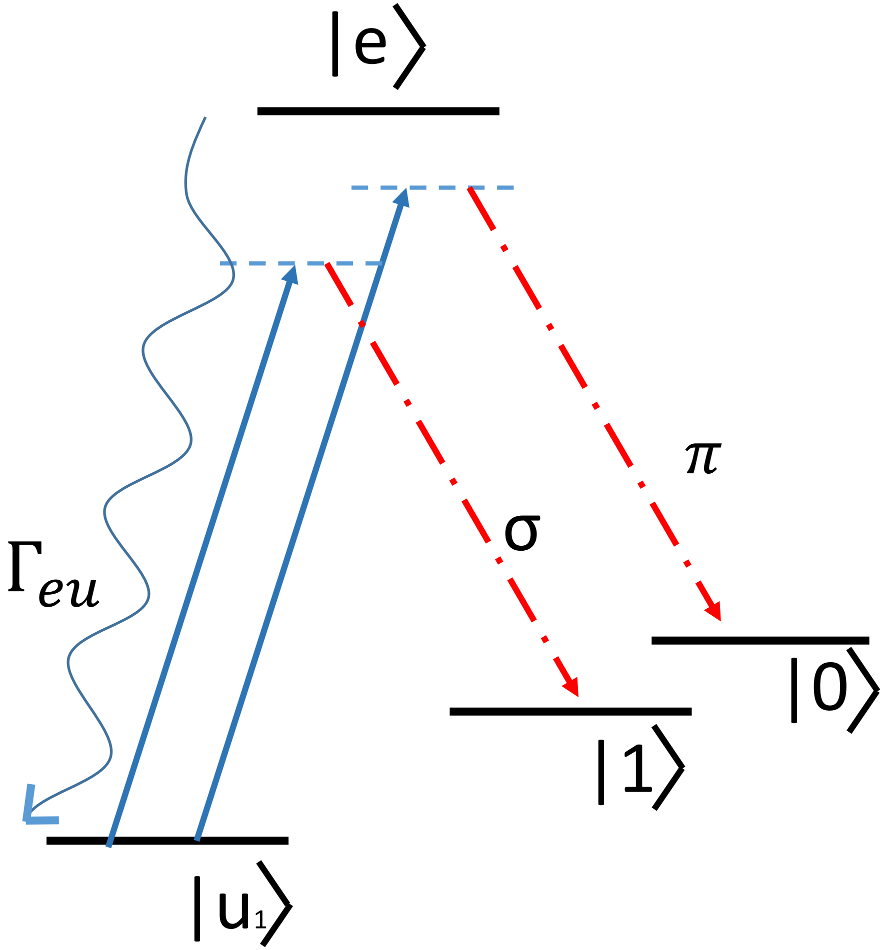

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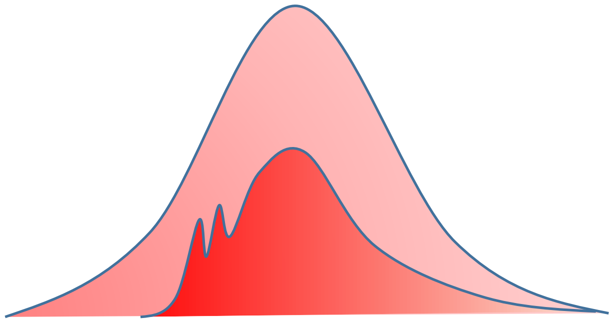

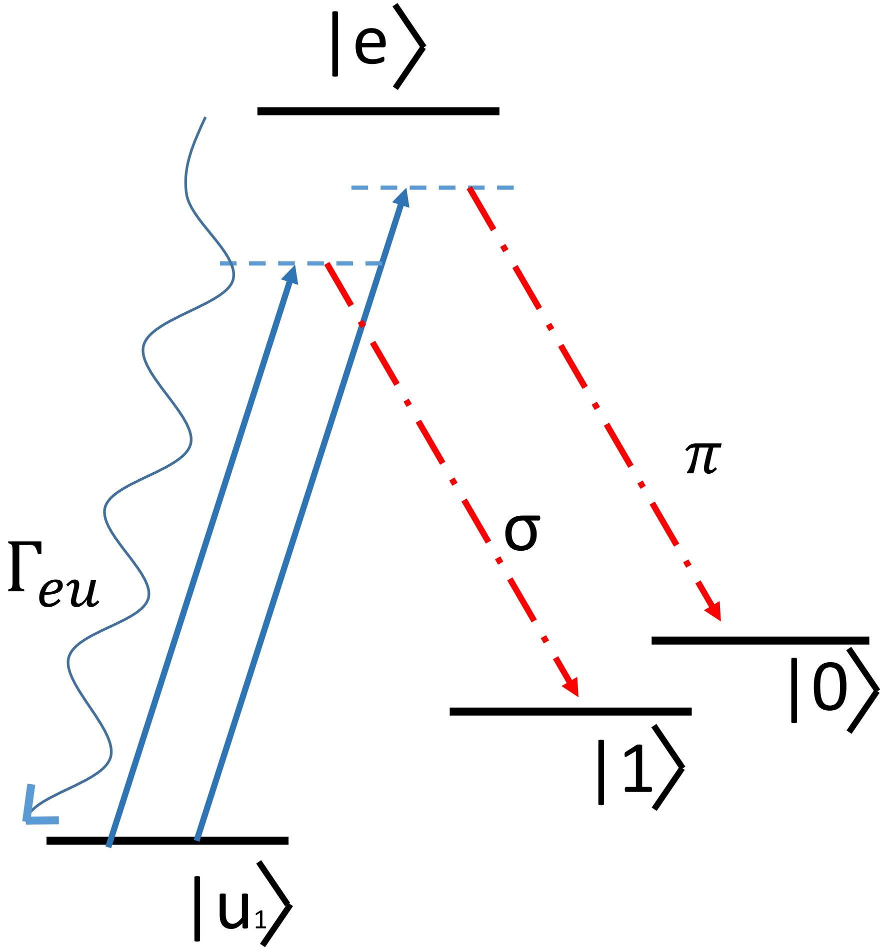

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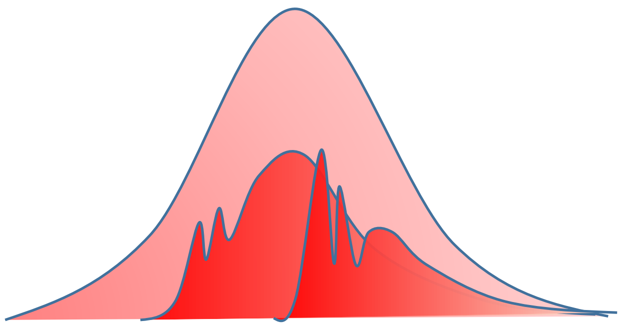

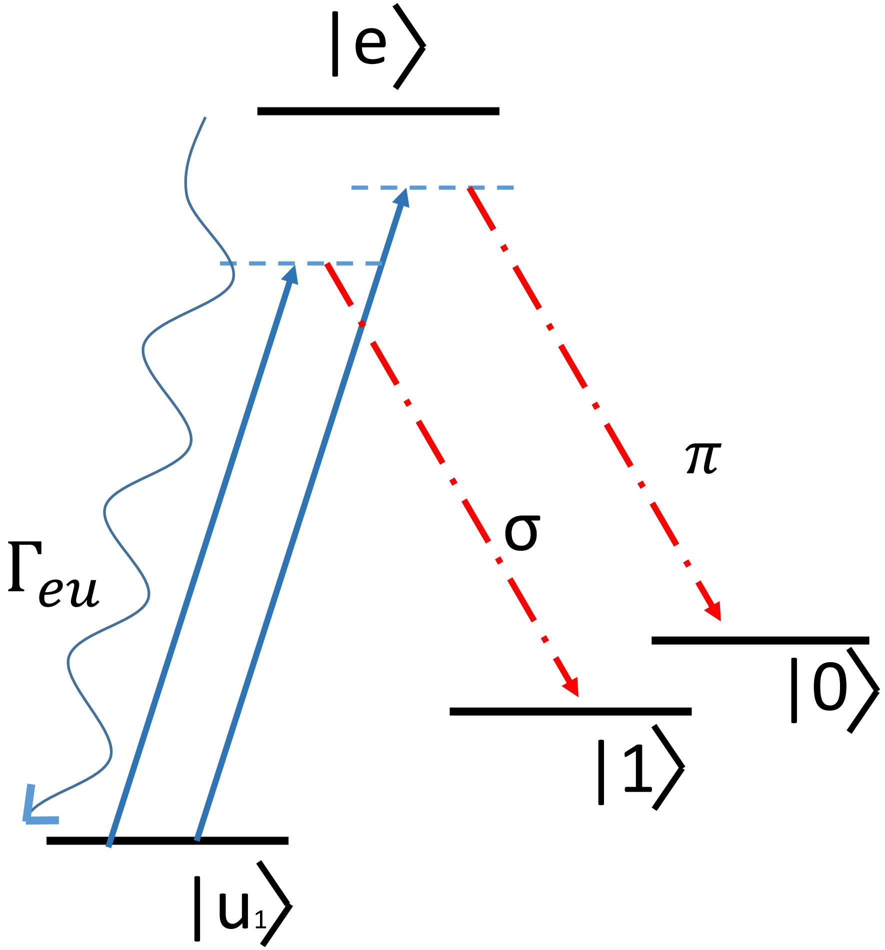

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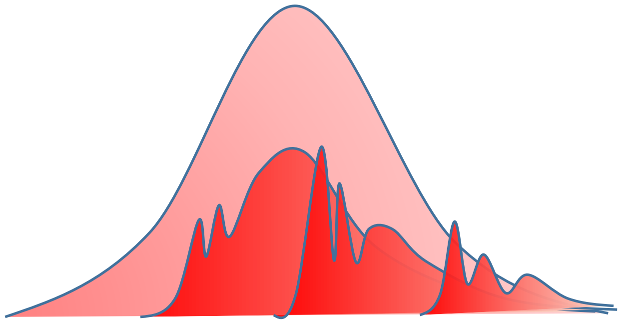

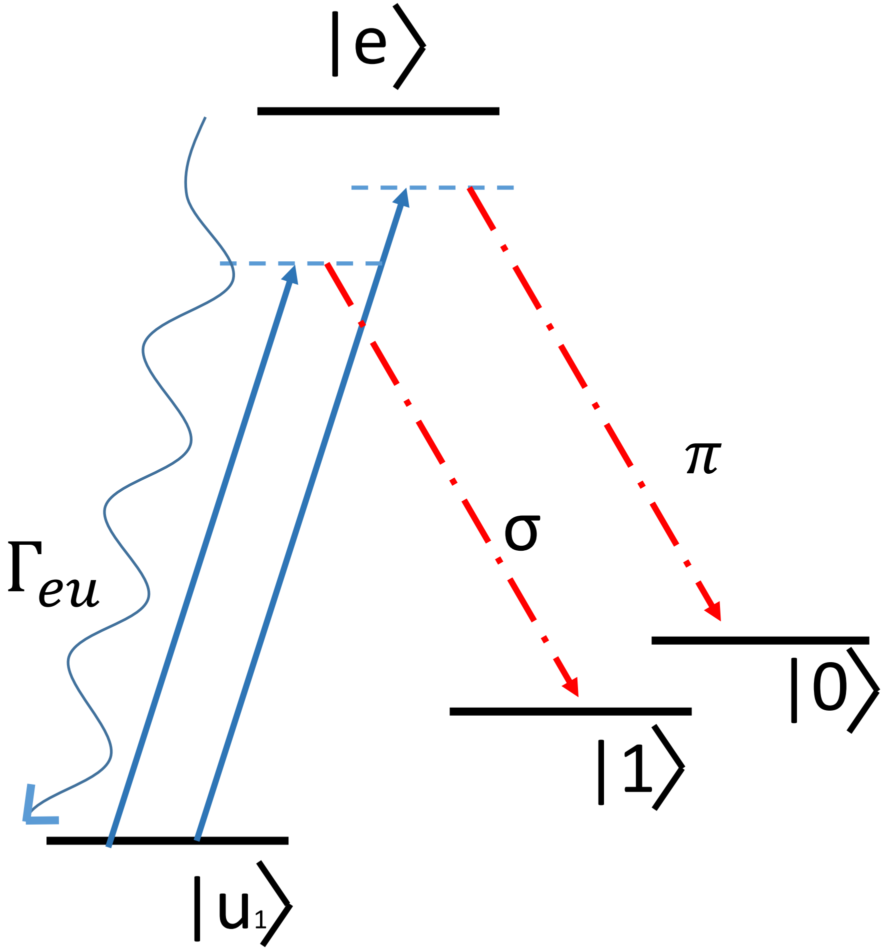

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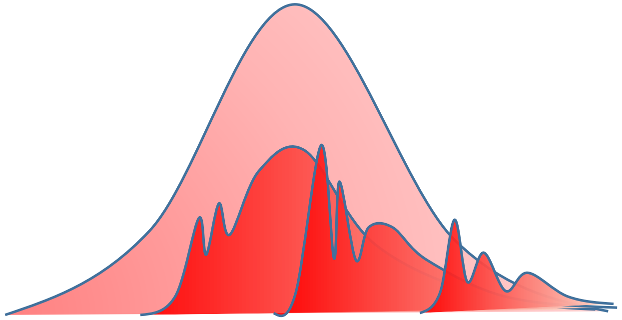
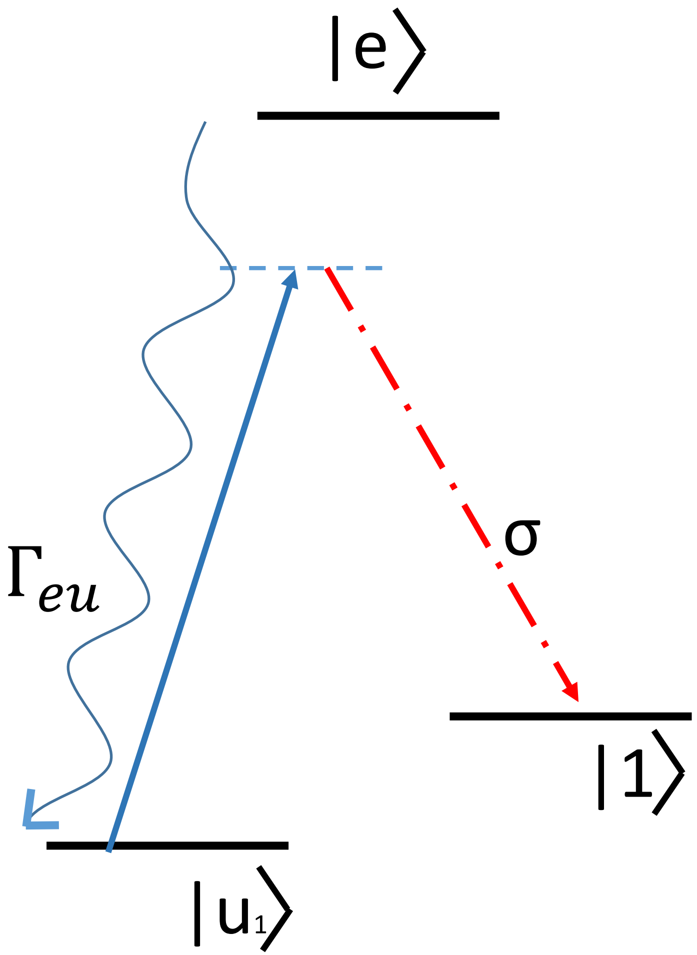


Two time correlation function:

$$f(t,t') = \langle \hat{E}^+(t)\, \hat{E}(t') \rangle$$



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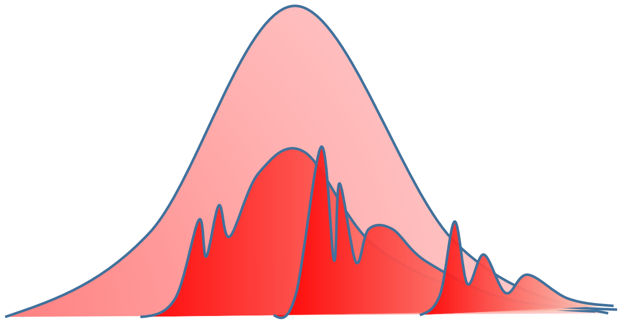

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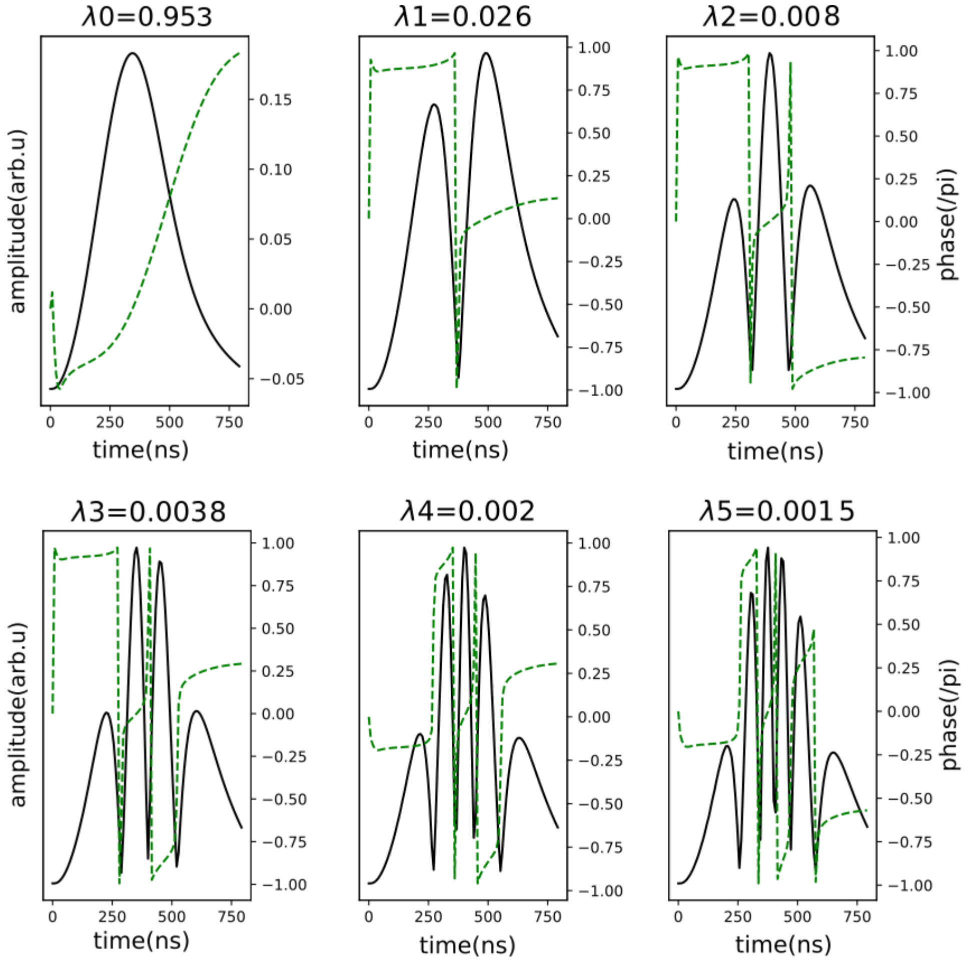

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Noise process and temporal property of photons

Temporal mode mixing for double Λ system:

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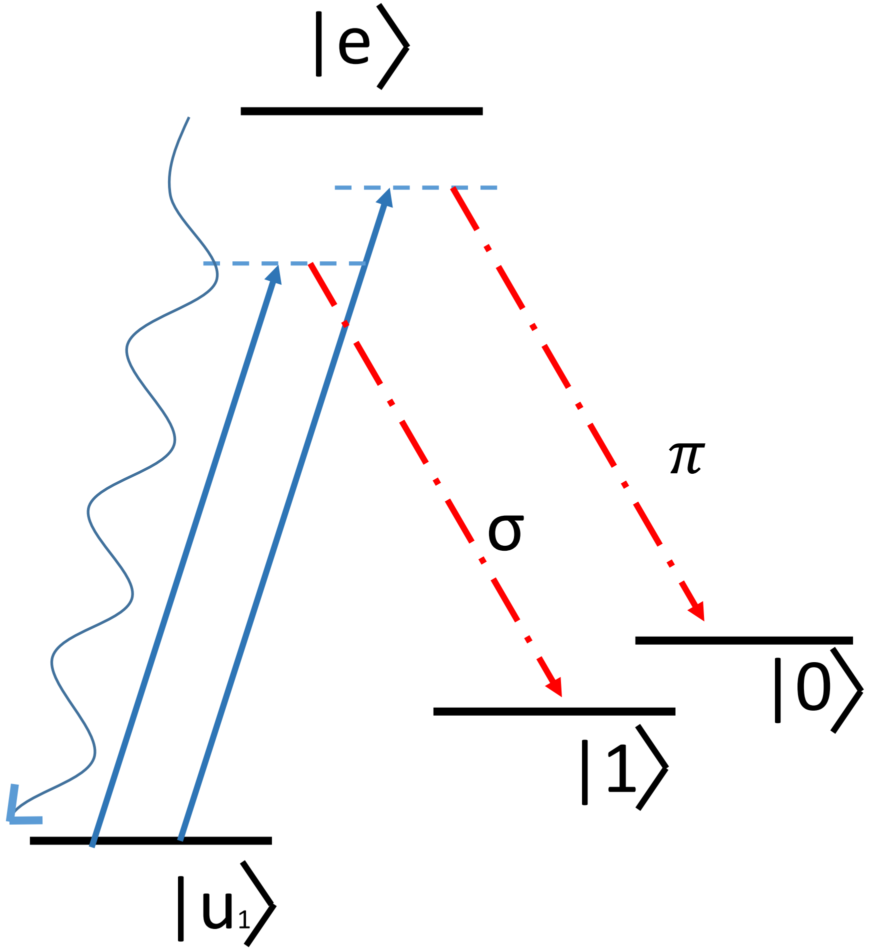

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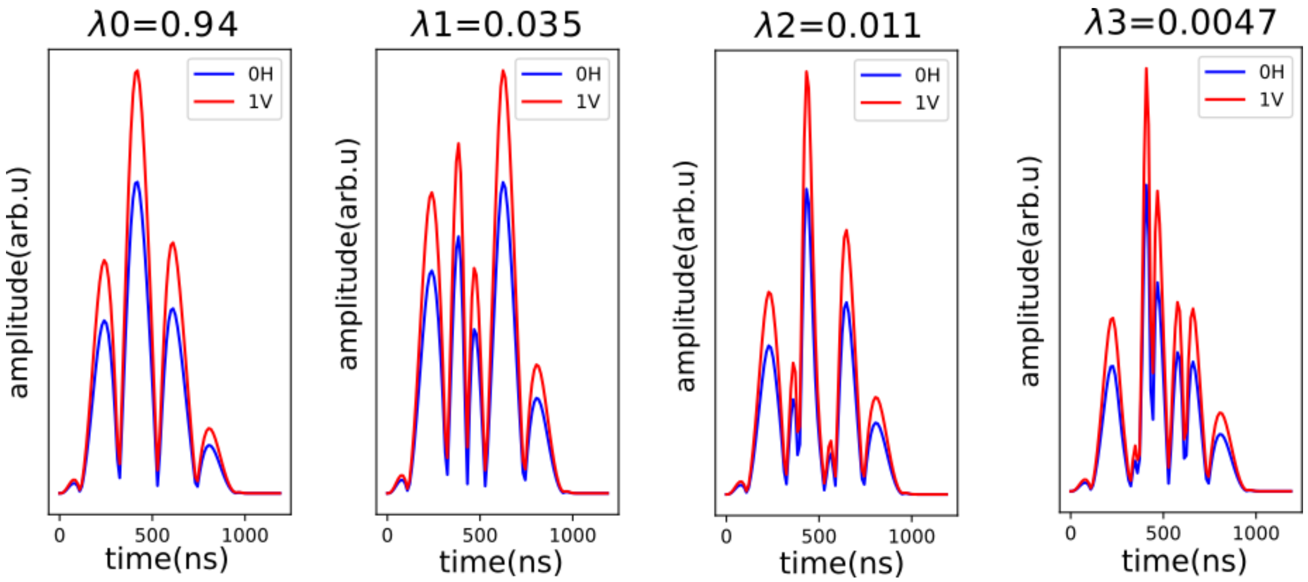

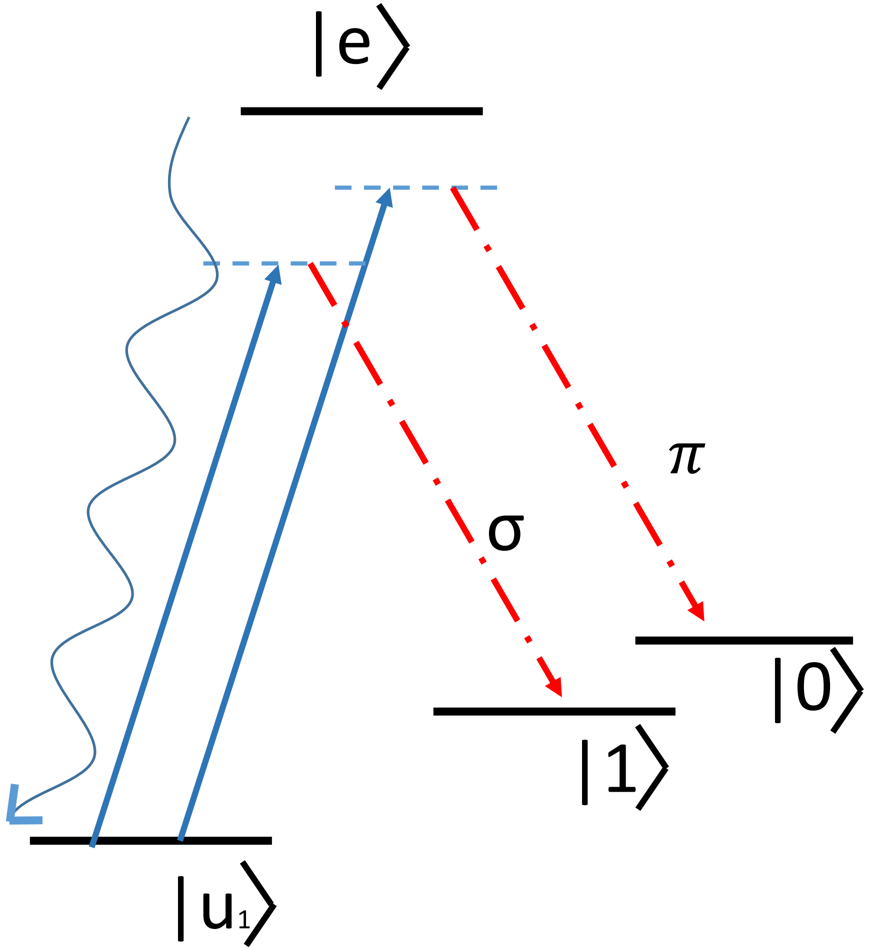

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- Optimising transmission, concentricity, and detection window

$$L = 400\mu m, D_{mirror} = 100\mu m, loss = 10ppm, B = 100G, misalignment = 700nm, \tau_{prep} = 0.5\mu s, \eta = 0.5$$

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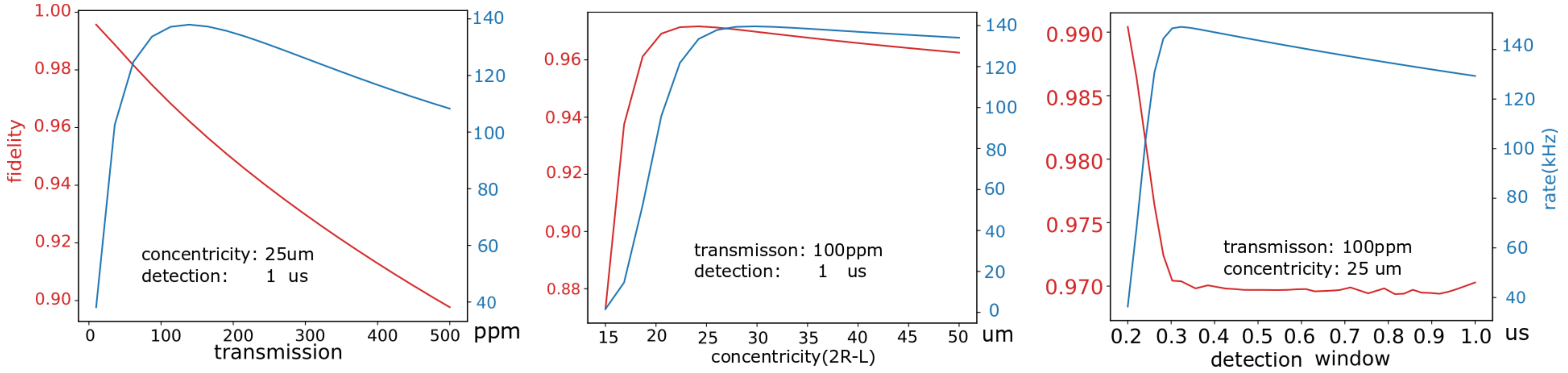

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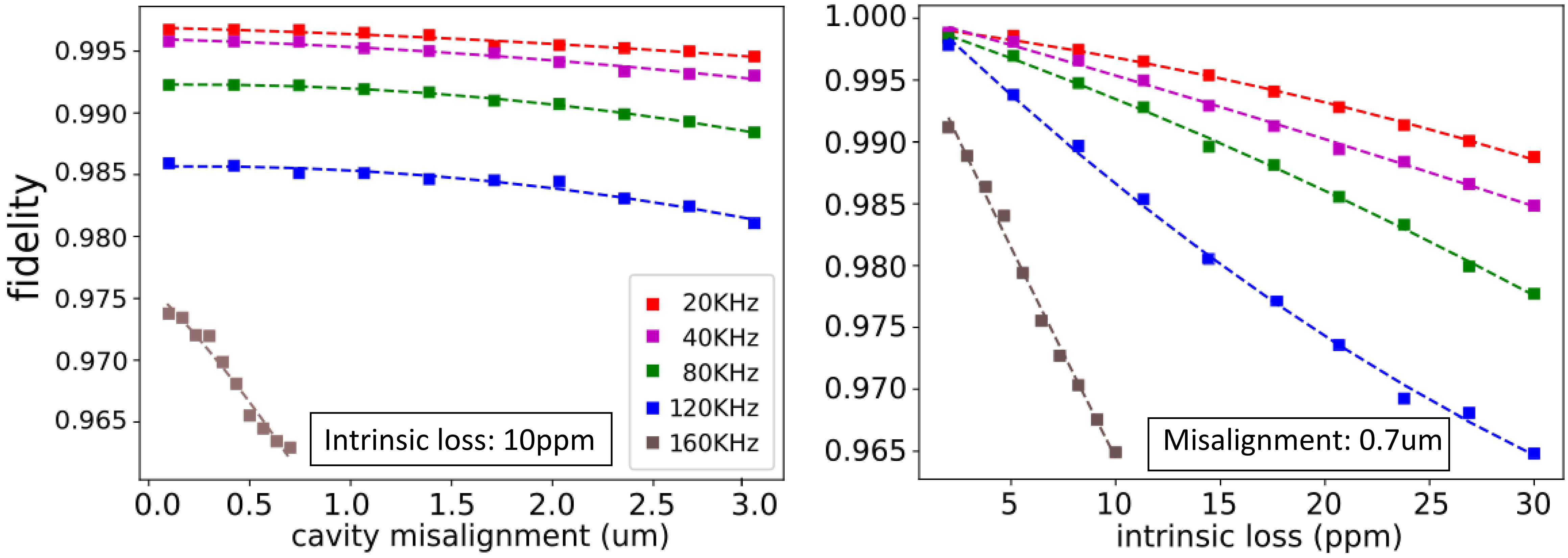
Technical challenges

- Best ion-ion entanglement performance with fabrication errors.



Summary and outlook

summary

- A solver to predict and optimise ion-ion remote entanglement regarding temporal mixing and Loss channel
- >100KHz Bell state rate and >98% fidelity can be achieved by reasonable fabrication errors

outlook

- Take birefringence into account
- Construct an analytical description

Thank you